



# VOLUME I - FINAL REPORT SUMMARY

Prepared Under Contract NAS 9-12503



For The  
Manned Spacecraft Center,  
National Aeronautics and Space Administration  
Houston, Texas

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AND SOLID WASTE PROCESSING FOR AEROSPACE  
AND DOMESTIC APPLICATIONS. VOLUME 1:  
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**STUDY OF WATER RECOVERY  
AND SOLID WASTE PROCESSING  
FOR AEROSPACE AND DOMESTIC  
APPLICATIONS**

**VOLUME I - FINAL REPORT SUMMARY**

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Houston, Texas**

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## FOREWORD

This document was prepared by the Grumman Aerospace Corporation under Contract NAS9-12503, "Water Recovery and Solid Waste Processing for Aerospace and Domestic Applications" for the Urban Systems Project Office, at the Manned Spacecraft Center of the National Aeronautics and Space Administration. It contains an abbreviated description of the contents of Volume II - Final Report. The program was administered under the technical direction of Mr. Rueben Taylor.

Information pertaining to water resources was provided by Geraghty and Miller, Consulting Ground Water Geologists.

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## INTRODUCTION

Land development in many parts of the country is discouraged by inadequate water resources or by incompatibilities between water supply and waste treatment plans. In addition, many established areas cannot readily keep pace with rapidly expanding urban populations without resorting to very expensive additions to their water supply and waste management systems. Practical alternatives are required in newly constructed or redeveloped communities where such difficulties exist.

During the past decade, the NASA, and aerospace and commercial industries have been concurrently advancing water and waste management technology. This study explores the application of advanced concepts for water recovery and solid waste processing systems for residential use. Its objective is to define a system concept which offers the best potential for near term and future usage. Concepts are developed and evaluated within the context of a total system that would provide all necessary utilities to a "free standing" community. For the purposes of this study a community model consisting of 500 newly constructed low rise apartment units with four (4) occupants per unit has been assumed.

The study was initiated with a regional overview of water resource factors as they affect new community planning. Determinations of residential water use and waste generation rates were also made.

Significant reductions in household water flow are readily achievable by appliances and fixtures currently being used in aircraft, marine, as well as mobile and remote home applications. A survey of this equipment was conducted. Surveys were made to accumulate data describing currently available water quality monitoring and control equipment, and water and waste processing systems. Aerospace versions of processing equipment were also reviewed to evaluate the contribution that this technology might make in the design and development of advanced systems.

Equipment and operating cost data was accumulated for those processes that were considered appropriate to the community model. Nineteen (19) concepts in four (4) categories, based on major process selections, were developed. The concepts incorporate varying degrees of water conservation, reuse and reclamation. They were evaluated by means of a straightforward comparison of total system costs, with some consideration given to water consumption. In order to avoid selection of a concept suitable only for small populations, the comparisons were extended to towns of 25,000 and 250,000. Water hardness was found to produce a significant cost variation as a result of differing detergent and/or water softening needs. Comparisons were therefore made for both hard and soft water areas. Projections were made to the year 2000 to assess any shift in relative cost due to differing rates of increase in the various system components.

A preliminary design of the selected concept was made. Specifications for selected components are presented along with an overall system schematic. The interfaces of the selected concept with a total energy system are identified. In an appendix, a cursory review of thermodynamic systems for power generation and their fuel consumption requirements are given.

## I WATER RESOURCES

Since the thrust of this study is aimed at small new communities, it assumes that ground water will be the source of potable water. The relationships between ground water, land use, water rights doctrines, and the compatibility of water supply and disposal of treated sewage on the same site are discussed. Areas with high potential for ground water sources are shown on maps of the contiguous United States. Areas with existing or emerging water resource problems in the U. S. are tabulated showing their type of problem(s).

The status of the quality of municipal drinking water is reported from a U. S. Public Health Service Survey. The systems surveyed represented five percent of the national total and served 12% of the national population. Sixteen percent of the systems exceeded mandatory limits of quality and should have their water rejected. Only 59% had completely acceptable water.

The daily per capita consumption of water varies considerably in the literature most probably because of the different bases on which the data are gathered or presented. Consumption is a function of personal characteristics such as income, property valuation, education, etc. as well as type of residence, disposal system, water charges and region of the country. Values of average flow and peak to average ratios are given. A "model" distribution of water within the household is presented in tabular form and estimates of hot water requirements are also tabulated.

## II WASTE GENERATION

The usual form of denoting the output of water borne wastes is in terms of concentration. This form is incomplete without specifying the quantity of water involved. In this study, where the volume of water is to be deliberately manipulated, it is more appropriate to designate the waste generation in terms of weight per capita per day.

A tabulation of waste generation rates by fixtures and appliances is presented. It was derived from a Swedish experimental apartment house and was adjusted to reflect American household practices. Another tabulation gives estimates of these outputs in the future.

The generation of solid wastes is reported in the literature with significant variation. It is a function of the degree of urbanization, type of dwelling and the income of the household. For this study, 3.5 lbs. per capita-day of residential refuse plus 0.5 lbs. per capita-day of commercial refuse were assumed. Twenty-five percent moisture was also assumed. Data is supplied showing seasonal variations and the composition of refuse.

### III COMMERCIAL EQUIPMENT SURVEYS

The amount of water consumed in dwellings can be reduced significantly without affecting personal habits or redesigning entire water and wastewater systems. This can be accomplished by the judicious selection of fixtures and appliances that inherently conserve water. A survey of commercially available low water consuming equipment was made which to some extent duplicated an earlier effort. Nevertheless, it was performed to preclude the omission of new developments.

Since toilets consume about 45% of the water used inside a typical dwelling, special attention was given to this item. Eight types of toilet systems and a dual flush mechanism are discussed. Other items included in the discussion are a kitchen sink garbage grinder, shower flow restrictor, clothes washers, and dishwashers. The potential for water conservation in both types of washing machines by rinse reuse is presented. With rinse reuse, the fresh, potable water that rinsed clothes or dishes, is stored and later reused in the next wash cycle of their respective machines. Schematics of the various systems are shown.

In a system where potable water is to be reclaimed from waste water, automatic monitoring instrumentation will be mandatory to assure health safety. This would apply even when water is upgraded to less than potable quality. Instruments are available in several styles based upon ruggedness, dependability, stability, service and calibration requirements. "Process instruments" are built and housed for long uninterrupted service in chemical plants, oil refineries and sewage treatment plants. "Laboratory instruments" also called scientific instruments, are usually much more sensitive and versatile but require frequent calibration by skilled operators. Between these extremes are a range of instruments with intermediate characteristics. They are often used for pilot plants or semiworks testing.

A survey of available process instruments was made, with the results shown in Table 1. A detailed discussion of water quality parameters, the methods of sensing them and a state-of-the-art review of sensors is presented. One approach to decreasing the dependence of recycle systems on adequate instrumentation is to select processes that can use simpler parameters to assure quality. For example, high temperature destruction of bacteria and viruses can be verified by monitoring temperature. For the purpose of this study, adequate instrumentation is assumed for all recycle methods.



#### IV. APPLICABLE AEROSPACE TECHNOLOGY

The importance of water and waste management in advanced manned spacecraft has motivated NASA and the aerospace industry to undertake many development programs in this area. For the most part, the resultant systems were extensions of processes that were developed for less demanding industrial and commercial applications. Complimenting the survey of commercially available low water consuming appliances and fixtures, a survey of appropriate spacecraft devices was made. Evaluations revealed that much of the sophistication of aerospace adaptations of water and waste treatment processes and equipment is a result of unique requirements for: zero gravity operation, extremely high reliability, minimum weight, volume and power utilization, limited supply and lack of disposal facilities. In general, their use requires a high degree of motivation that is unlikely in ordinary household situations.

## V COMMUNITY MODEL

In order to make a consistent assessment of the various concepts, a housing model is required. An apartment complex, similar to that used by NASA in a recent report on Advanced Housing Development is used. The basic characteristics of the model are:

- population of 2000
- five hundred apartment units
- twenty six apartment buildings
- average of almost twenty units per building
- fifty two acres total
- twenty five acres of landscaping
- layout of buildings as shown in Figure 1
- level terrain

To avoid limiting the evaluation to small populations, the economic analyses are conducted for "towns" of 25,000 and 250,000 people as well as the community of 2000. The towns are comprised of 12-1/2 and 125 model communities tightly surrounding a central district as shown in Figures 2 and 3. While it is recognized that larger towns would not be layed out in this manner, the models provide a convenient and representative means of evaluating larger populations.

The equipment for processing water, waste water and refuse is always considered central to the population under study. That is, for a population of 2,000, the water reclamation equipment, refuse incinerator, etc. is located on site. For 25,000 or 250,000 people, this equipment is in the center of town.

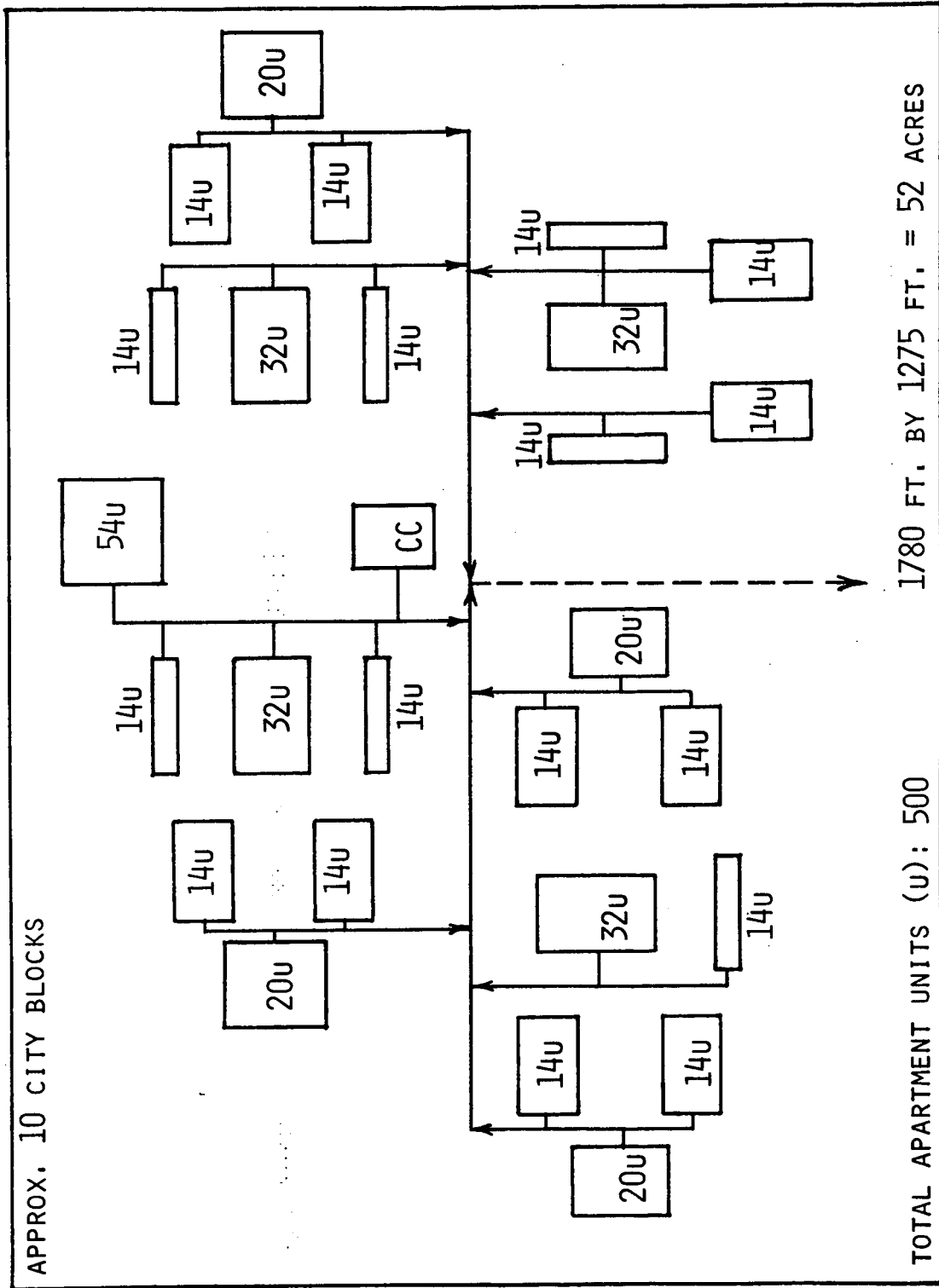


Figure 1 Community Model - 2000 Population

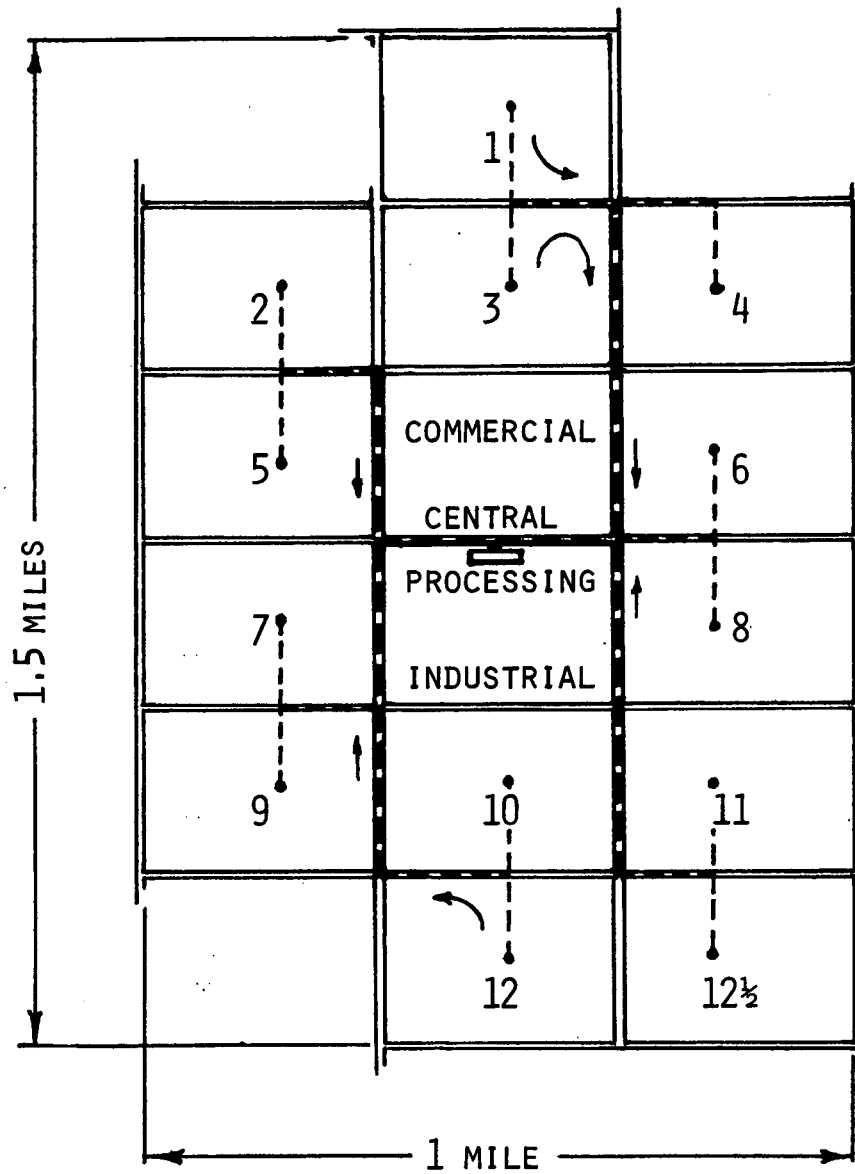


Figure 2 Town Model - 25,000 Population

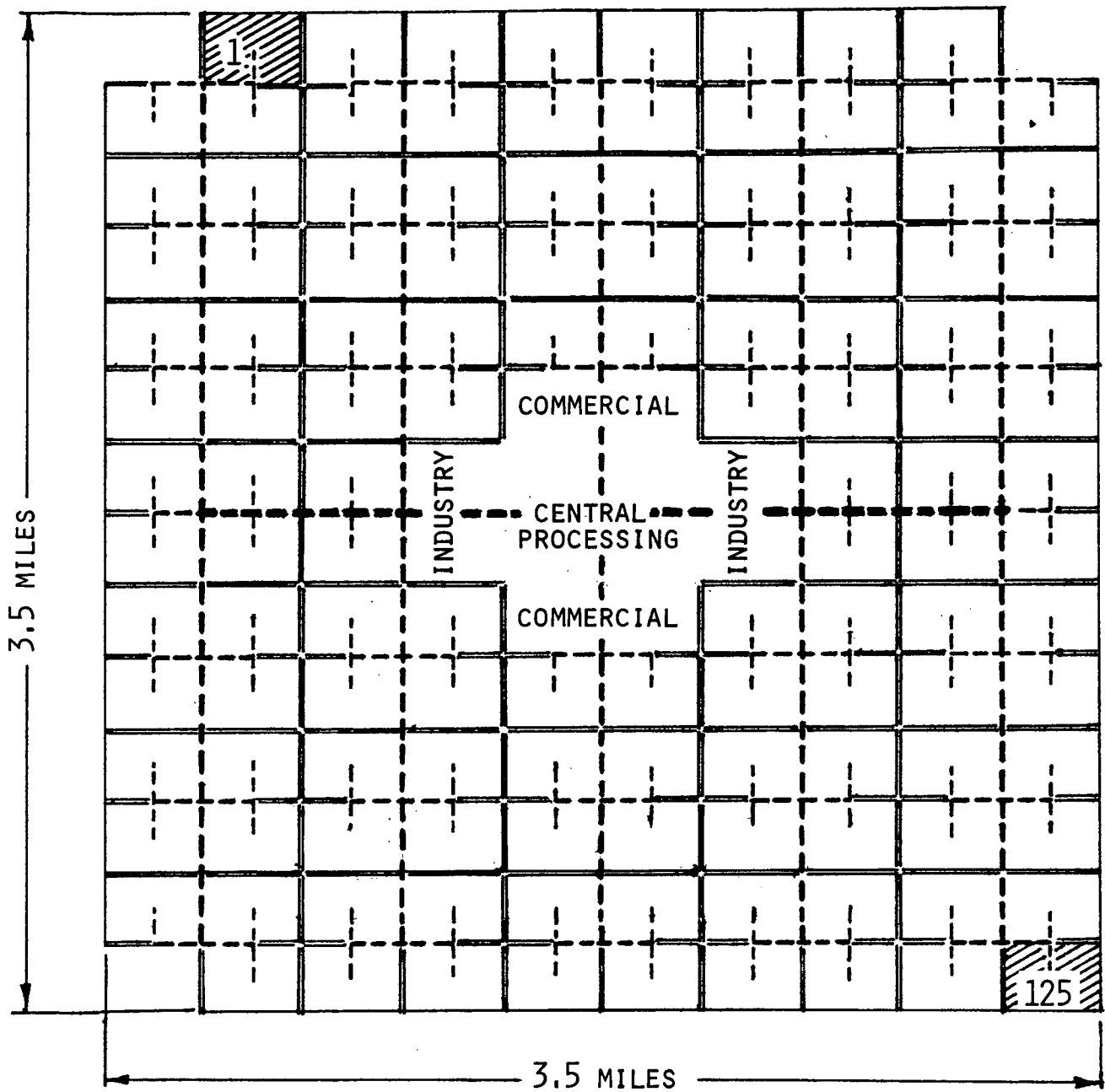


Figure 3 Town Model - 250,000 Population

## VI COST EVALUATION DATA

This section contains cost data in processed form for ease of use in assembling total system costs. It includes subsystem, subassembly and component costs, especially when they are used in more than one concept or with varying capacities.

General cost factors that are examined are:

- **Subsidies:** Governmental subsidies (e.g. for sewage systems) are ignored. The full cost of a concept is considered regardless of who pays for it, or when.
- **Cost of Finance:** Most equipment costs are amortized for thirty (30) years at 5% interest.
- **Cost Index:** This information permitted updating cost data to the current year, as well as allowing for cost increases to the year 2000.
- **Local Site Effects:** In keeping with the generalized approach of determining a concept that is applicable to most areas of the country, the cost effects of regional influences such as terrain, climate, labor costs are ignored. National averages are used when possible.
- **Industrial Sewage:** Residential sewage only is considered.

Systems that collect and transport sewage represent the major cost of sewage treatment. They are examined firstly for conventional flow systems and then for reduced flow systems. Much data for the former is available from the EPA and is presented in tabular form showing the annual per capita cost as a function of population size for the years 1972 to 2000. Separate tables are used for collection sewers and interceptor/outfalls. Reduced flow sewage costs were calculated for gravity transport systems and for vacuum transport systems, using the community and town models as a basis. Vacuum sewers, which are used only on the community site (of 2000 people), were configured for separate black-gray water usage and for gray water only.

The cost of waste water treatment was handled in three categories. Biological treatment costs were obtained from the EPA and publications by its members, and contractors. Capital costs and operating/maintenance costs are tabulated as a function of population for the years 1972 to 2000, as annual per capita cost. The other two categories are physical-chemical treatment processes, one for black water and one for gray water. The black water process selected is coagulation-sedimentation followed by charcoal absorption and the gray water process selected features reverse osmosis membranes. The phys-chem cost information totals are presented in graphic form as a function of flow rate.

Cost data for the following components and subsystems are presented either in graphic form as total cost per unit of flow or as finite costs:

- **Distillation: Simple thermal distillation and vapor compression**
- **Effluent Disposal: On site disposal by storage pond (spreading basin) and by tile field**
- **Refuse Collection**
- **Disposal: Incineration with integral heat recovery and wet oxidation**
- **Toilets**
- **Grease Separation**
- **Wash Water Flush Units**
- **Washing Machines (clothes and dishes)**
- **Cleansing Agents**
- **Water**

## VII INTEGRATED SYSTEM CONCEPTS

The overall objective of the concept development task was to devise an integrated water and solid waste management system that would minimize water requirements and sewage and solid waste disposal, all within the constraint of economic practicality. Although consideration of total utilities systems (on-site electric power generation with waste heat utilization) is not within the scope of this program, semi-quantitative attention is given to their interactions with water and waste management system concepts.

The method used to establish the system concept for which a preliminary design was made is:

- identification of major water consuming operations
- identification of major treatment and disposal problems
- subjective selection of methods to minimize the above
- generation of combinations of these methods
- economic evaluations of the combinations
- selection of the most economic combination, compatible with minimum water consumption

The ground rules that are used in developing system concepts are as follows:

- Potable drinking water is always available under pressure from an undefined municipal supply system.
- Waste water can be collected and treated in either of two approaches: all waters are collected and treated in a single process, or toilet wastes (black water) are collected and treated by one process and all other waste waters (gray water) are collected and treated by another process.
- Gray water can be reused for toilet flushing or irrigation without treatment except for disinfection.
- Water reclaimed (recycled) from gray water can be used for bathing or laundering but not for internal consumption, food preparation or glassware cleaning (kitchen functions).
- Water will not be reclaimed for household reuse from black water. The effluent of a black water treatment process may, however, be used for irrigation.
- Water will not be reclaimed for household reuse if there are community water needs that can be satisfied by wastewaters.
- Thermal reclamation systems will utilize waste heat only. Heat will not be generated for the specific purpose of water reclamation.
- Storm sewers and water for fire protection will not be included in concept development or cost evaluations. These considerations would be part of a community or town design regardless of the water and waste management system configuration.

The approaches used for various aspects of concept development are discussed in some detail. The topics include: water conservation, toilets, gray water toilet flush, rinse water reuse, landscape gray water irrigation, black water treatment, waste water transport and refuse disposal.

The nineteen system concepts that are defined for further evaluation do not represent a complete matrix of process and component selections. Some concepts had water imbalances or had obvious economic disadvantages when compared to other concepts being generated. A complete set of concept schematics are presented in Appendix A of Volume II. Typical schematics from three concept categories are illustrated in Figures 4 through 7.

All nineteen concepts are evaluated by means of a straightforward cost comparison, with some weight given to water consumption. Cost summaries for the four typical concepts are presented for the current time period. The text of Volume II contains the cost summaries for all nineteen concepts, while Appendix A contains these same summaries projected to the year 2000. All summaries are made for populations of 2,000, 25,000, and 250,000 people. The components of the cost summaries are:

Water Fixtures	Grease Separator
Toilet	Incinerator
Wash Water Toilet Flush Unit	Phys-Chem for Gray Water
Clothes Washer	Phys-Chem for Black Water
Dishwasher	Bio-treatment with AWT
Internal Building Piping	Distillation
Renovated Water Return Lines	Municipal Outfall Line
Vacuum Collection Sewer	Cleaning Agents
Black Water Sewer	Water - Building, Internal
Gray Water Sewer	Water - Irrigation
Combined Sewage Sewer	Municipal Water Softening
Refuse Collection	R.O. Concentrate Lines
	Storage Ponds

There is no one concept that is least expensive under all conditions. For soft water areas, concepts that conserve, but do not recycle water are least costly. For hard water areas, minimum costs are achieved by concepts such as B-10 which recycle gray water during periods of the year when there are no irrigation requirements. Since the need for a water and waste management system will be strongest in water short areas and these areas tend to have hard water, the choice gravitated towards concept B-10.

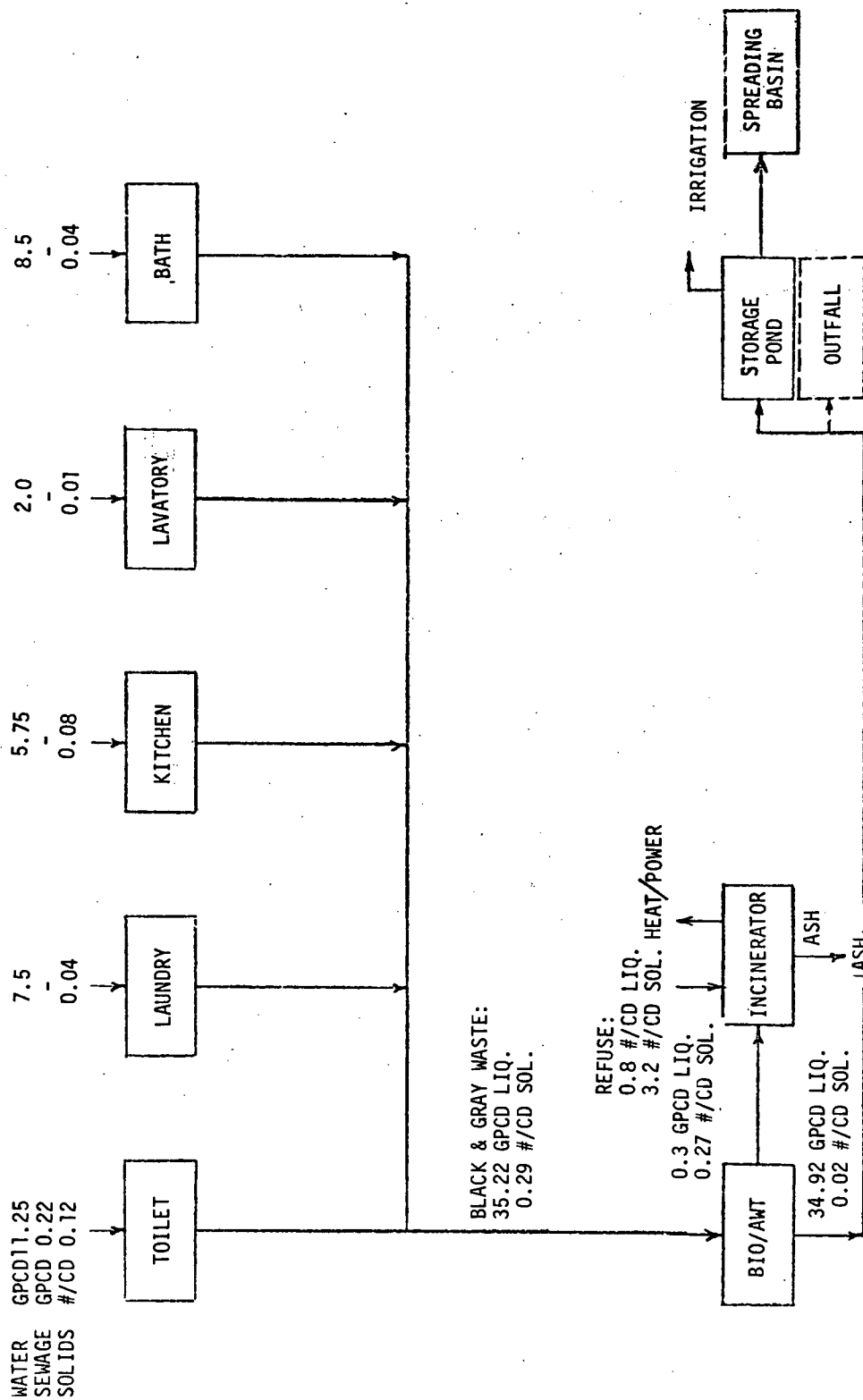


Figure 4 Baseline Concept (A-2)

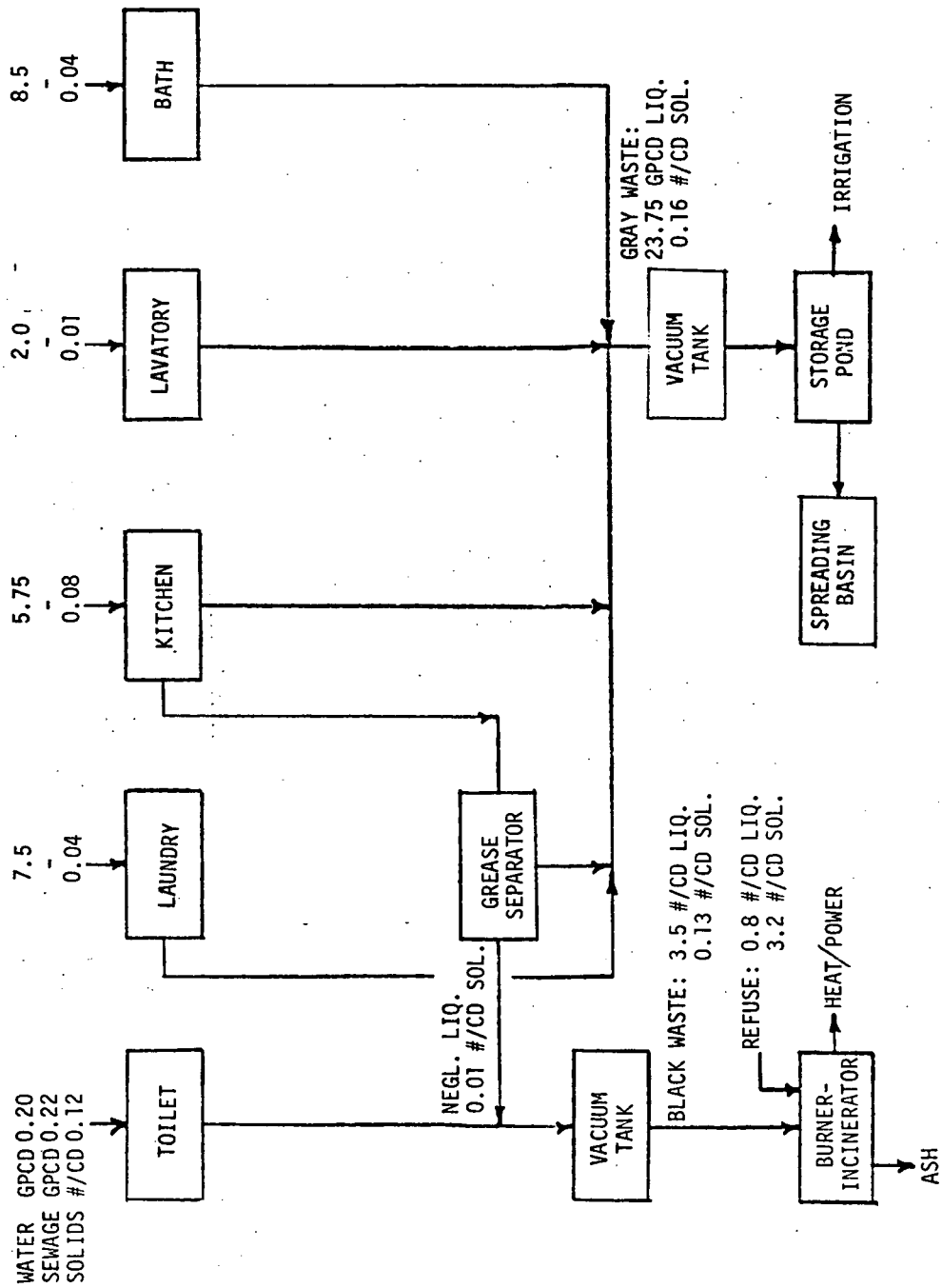


Figure 5 Typical Vacuum Collection Concept (B-1)

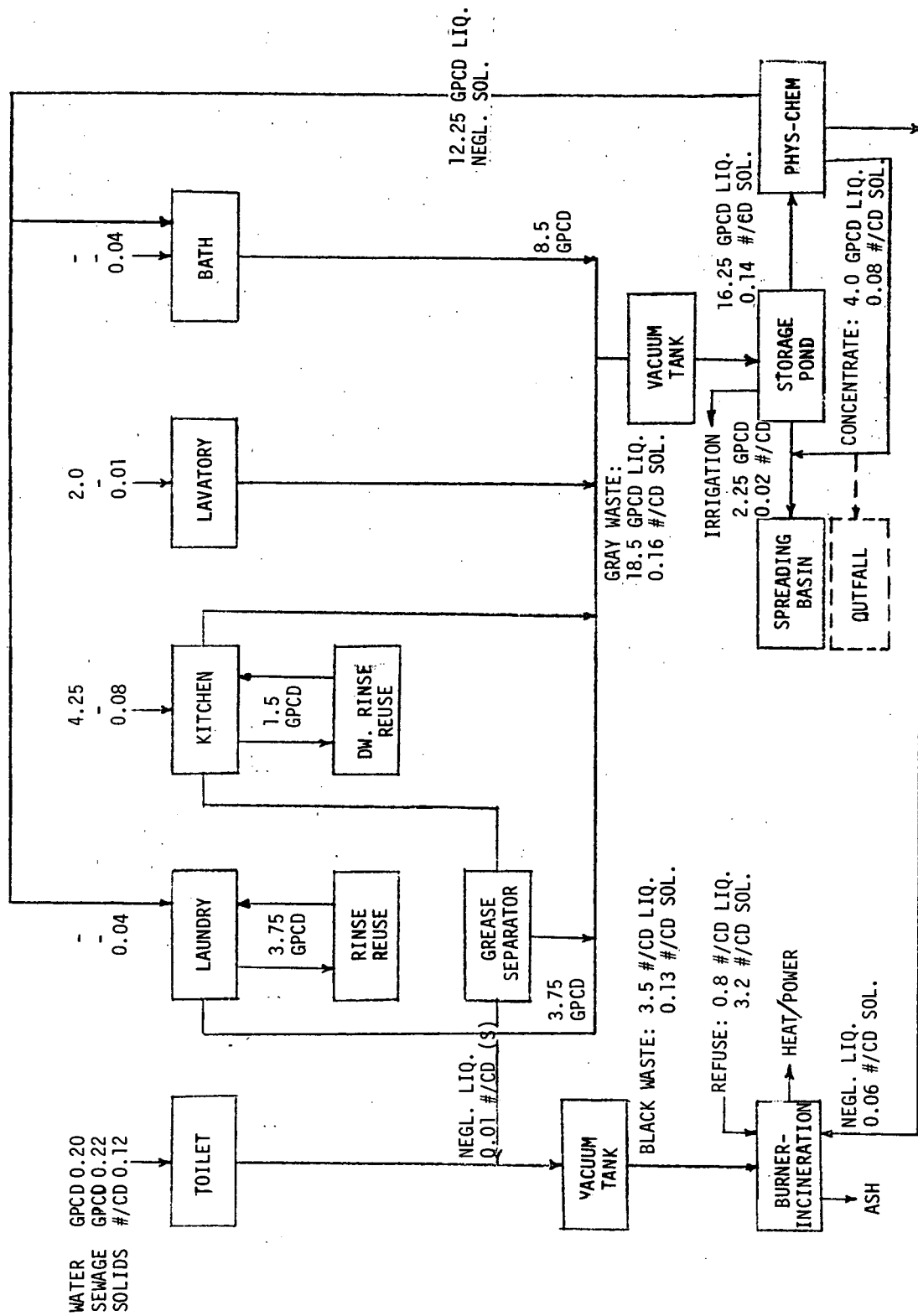


Figure 6 Typical Recycle Concept (B-10)

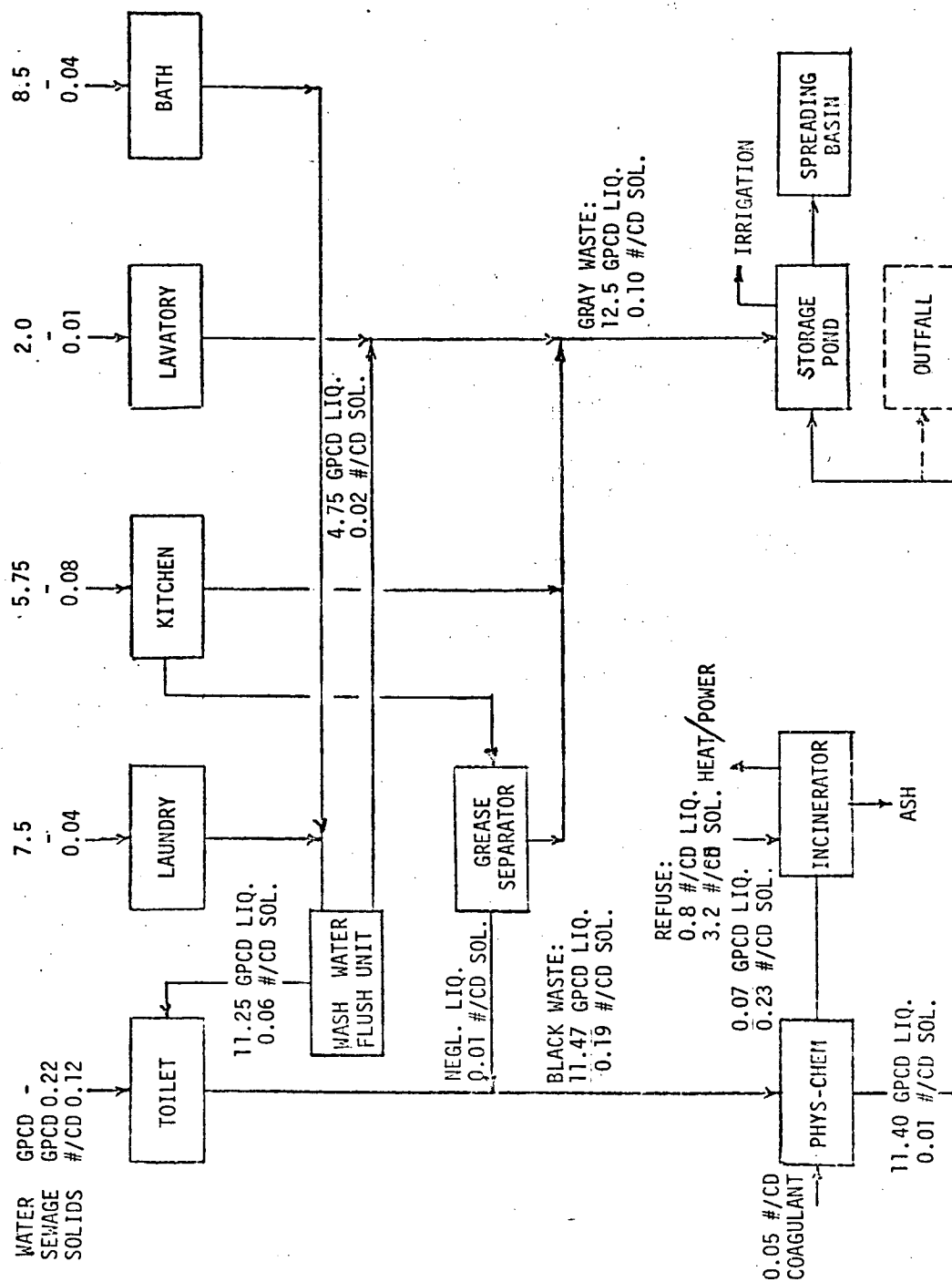


Figure 7 Typical Wastewater Flush Concept (C-1)

TABLE 2. CONCEPT COST COMPARISONS

CONCEPT	A-2						B-1						B-10						C-1					
	2,000		25,000		250,000		2,000		25,000		250,000		2,000		25,000		250,000		2,000		25,000		250,000	
	\$/FY	%	\$/FY	%	\$/FY	%	\$/FY	%	\$/FY	%	\$/FY	%	\$/FY	%	\$/FY	%	\$/FY	%	\$/FY	%	\$/FY	%	\$/FY	%
POPULATION																								
1. Water Fixtures	29.2	9.1	29.2	9.6	29.2	10.2	29.2	10.5	29.2	11.2	29.2	11.4	29.2	11.4	29.2	11.4	29.2	11.4	29.2	11.4	29.2	11.4	29.2	11.4
2. Toilet	12.2	3.8	12.2	4.0	12.2	4.3	25.8	9.2	25.8	9.8	25.8	10.0	25.8	10.0	25.8	10.0	25.8	10.0	25.8	10.0	25.8	10.0	25.8	10.0
3. Wash Water Toilet Flush Unit	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4. Clothes Washer	3.0	0.9	3.0	1.0	3.0	1.1	3.0	1.1	3.0	1.2	3.0	1.2	3.0	1.2	3.0	1.2	3.0	1.2	3.0	1.2	3.0	1.2	3.0	1.2
5. Dishwasher	27.0	8.4	27.0	8.8	27.0	9.5	27.0	9.7	27.0	10.3	27.0	10.5	27.0	10.5	27.0	10.5	27.0	10.5	27.0	10.5	27.0	10.5	27.0	10.5
6. Building Internal Piping	7.7	2.4	7.7	2.5	7.7	2.7	16.6	5.8	16.6	6.1	16.6	6.3	16.6	6.3	16.6	6.3	16.6	6.3	16.6	6.3	16.6	6.3	16.6	6.3
7. Renovated Water Return Lines	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8. Vacuum Collection Sewer	-	-	-	-	-	-	20.1	7.2	20.4	7.8	20.4	7.9	20.1	6.3	20.4	6.7	20.4	7.2	-	-	-	-	-	-
9. Black Water Sewer	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10. Gray Water Sewer	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11. Combined Sewage Sewer	26.4	8.2	33.7	11.0	37.0	13.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12. Refuse Collection	30.0	9.3	30.0	9.8	30.0	10.5	30.0	10.7	30.0	11.5	30.0	11.7	30.0	11.7	30.0	11.7	30.0	11.7	30.0	11.7	30.0	11.7	30.0	11.7
13. Grease Trap	-	-	-	-	-	-	1.8	0.6	1.8	0.7	1.8	0.7	1.8	0.7	1.8	0.7	1.8	0.7	1.8	0.7	1.8	0.7	1.8	0.7
14. Incinerator (Refuse and Sludge)	49.0	15.3	31.0	10.2	26.2	9.2	48.6	17.4	30.7	11.7	25.9	10.1	49.0	15.3	31.0	10.2	26.2	9.2	48.6	15.5	30.7	10.2	25.9	8.9
15. Phys-Chem. For Gray Water	-	-	-	-	-	-	-	-	-	-	-	-	37.6	11.7	26.0	8.6	13.1	4.6	-	-	-	-	-	-
16. Phys-Chem. For Black Water	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17. Bio-Treatment with AMT	55.6	17.3	33.2	10.9	20.4	7.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
18. Distillation	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19. Municipal Outfall Line	-	-	9.3	3.0	3.2	1.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20. Cleaning Agents (Soft Water Area)	58.0	18.1	58.0	19.0	58.0	20.4	58.0	20.7	58.0	22.1	58.0	22.6	58.0	18.1	58.0	19.2	58.0	20.5	58.0	18.4	58.0	19.3	58.0	19.9
21. Water: Building, Internal	20.4	6.3	20.4	6.7	20.4	7.2	14.0	5.0	14.0	5.3	14.0	5.4	3.8	1.2	3.8	1.3	3.8	1.4	13.9	4.4	13.9	4.6	13.9	4.8
22. Water: Lawn Irrigation	0.5	0.2	10.6	3.5	10.6	3.7	3.7	1.3	3.7	1.4	3.7	1.4	8.8	2.7	10.6	3.5	10.6	3.7	3.7	1.2	7.0	2.3	7.0	2.4
23. Municipal Water Softening (R.O.)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24. R. O. Concentrate Distribution System	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
25. Storage Ponds	2.2	0.7	-	-	-	-	1.8	0.6	1.8	0.7	1.8	0.7	1.6	0.5	1.6	0.5	1.6	0.6	1.8	0.6	1.4	0.5	1.4	0.5
TOTAL: SOFT WATER AREA	321.2	100.0	305.3	100.0	284.9	100.0	279.6	100.0	262.0	100.0	257.2	100.0	320.4	100.0	302.8	100.0	283.6	100.0	314.4	100.0	300.4	100.0	291.8	100.0
ADDITIONAL FOR HARD WATER AREA	58.0	-	53.0	-	58.0	-	58.0	-	58.0	-	58.0	-	-	-	-	-	-	-	58.0	-	-	-	58.0	-
TOTAL: HARD WATER AREA	379.2	-	363.3	-	342.9	-	337.6	-	320.0	-	315.2	-	320.4	-	302.8	-	283.6	-	372.4	-	358.4	-	349.8	-

## VIII PRELIMINARY DESIGN

This section describes the preliminary design of the selected water recovery and solid waste processing system concept. The only process variation from concept B-10 is in the use of a separate black water burner rather than incorporating this function into the refuse incinerator. The winter and summer mass balances for the preliminary design also show minor changes from B-10. Figure 8 depicts the detailed schematic of the preliminary design. It illustrates the interrelationships between the major functional elements of the system. Black water is concentrated in vacuum toilets, transported directly to vacuum receivers located in the center of the community, and incinerated on a more or less continuous basis. Gray water is accumulated in each apartment building and periodically transported to separate central vacuum receivers. Each apartment is also equipped with a tube settler designed to separate solids and grease and periodically discharge them to black water vacuum lines. Gray water is then pumped to a small storage pond or tank. A spreading basin is also provided to accommodate periods when the gray water supply exceeds the demand.

During growing seasons, landscape irrigation requires a greater quantity of water than the community consumes. As a result, gray water is directed during these periods to a subsurface irrigation network. During periods when irrigation is not required, gray water is directed to reclamation equipment where it is treated to potable quality and reused for clothes washing and bathing. Reclamation is accomplished by a treatment process that features reverse osmosis membranes.

Discussion of the design rationale is presented in the text for the following subsystems:

- Direct Household Reuse
- Apartment Building Collection
- Central Vacuum Collection
- Gray Water Storage and Disposal
- Subsurface Irrigation
- Gray Water Recovery
- Reclaimed Water Delivery
- Estimated Quality of Recovered Water
- Black Water Burner and Refuse Incinerator
- Typical Power and Energy Utilization Plant

Following these discussions are design and performance characteristics for nineteen major components and assemblies.

The preliminary design developed by this study is generally applicable to all regions of the country. It is compatible with a wide variety of total energy systems and offers distinct advantages when the two systems are integrated. As an example, in a 500 dwelling unit community, pond water that is used for scrubbing combustion exhaust gas from the power plant and incinerator, can recover 2.5 million gallons of water a year (3.5 gpcd) that would normally be given up to the atmosphere.

Although the preliminary design was not priced in detail, cost estimates were made for numerous concepts, preparatory to selection for the preliminary design. The concept which is the basis for the preliminary design is:

- 13% less costly in 1972 for soft water areas,
- 26% less costly in 1972 for hard water areas,
- 20% less costly in 2000 for soft water areas,
- 29% less costly in 2000 for hard water areas

than a conventional water and waste management system. The concept requires

- 56% less water for a 500 dwelling unit community
- 63% less water for towns of 25,000 and 250,000 people.

The concept produces

- 86% less treated sewage outfall flow for towns of 25,000 and 250,000 people.

Aside from the potential cost savings of a water and waste management system that makes use of up-to-date technology and a systems approach, housing developments can benefit by substantial reductions in their ecological impact. They can be located on land that is prospectively cheaper. Housing can also be situated in better compliance with planned economic development in water short regions or those that have pollution problems.

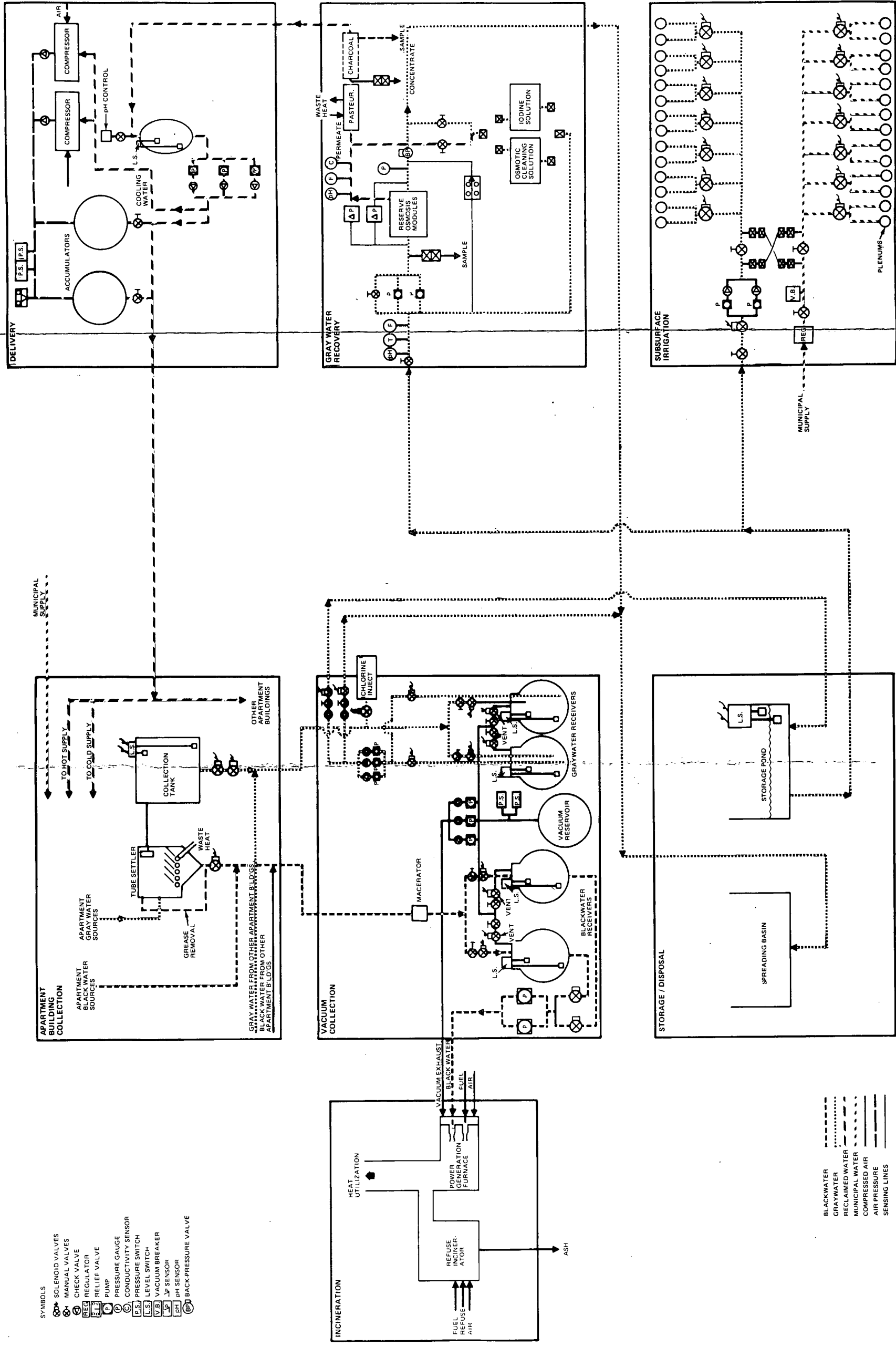


Figure 8 Water Recovery and Solid Waste Processing System Schematic

## IX. CONCLUSIONS

### I. WATER RESOURCES

- Local geography, geology, hydrology and climate play dominant roles in the development of water and waste management system configurations. Since a site location was not specified for this study, it was necessary in some instances to generalize environmental interfaces.
- Irrigation requirements also influence system design. In an average climate, lawn watering needs exceed gray water production during nearly half of the year. Subsurface gray water irrigation was found to be an effective means of reducing recycle requirements and beneficially disposing of wash waters.
- Water hardness has a significant effect on both household effluent quality and system cost. Reclamation processes soften water, resulting in decreases in detergent and/or softening costs in hard water areas of up to \$60 yearly for each family. In general, the water supplies in arid areas are hard. This increases the suitability of recycle systems to water-short areas.
- Present and near term projections of public, medical and legislative attitudes toward water reuse strongly suggest that some restrictions be imposed on the use of recycled waste waters in initial systems. As a result, none of the concepts considered use recycled black water for other than landscape irrigation. Even for this application, the black water is treated first to at least tertiary quality and then applied to the soil via sub-surface watering techniques. Recycled gray water, although potable, is not considered for routine internal consumption. It is used for laundry, bath and irrigation purposes only, in various concepts.
- With the rapidly increasing emphasis on new towns, new communities and planned unit development (PUD), water supply practices will probably change markedly. One effect will be a trend towards reduced per capita consumption through widespread use of low water consumption devices. In addition, the practicality of water recycling in new developments will result in considerable decreases in fresh water usage. However, recycle systems will be more expensive by reason of extra equipment and plumbing. Dividing this increased cost by fewer gallons consumed per capita will make water costs seem to be very high. If recycle systems are economically justified, it will be as a result of savings in sewage treatment and refuse and thermal management.

### II. WASTE GENERATION

- Estimates of water-borne and solid waste generation vary widely with such factors as level of affluence, social and personal habits, climate and housing. Empirical data is limited and difficult to correlate.

A recent Swedish experiment, which instrumented apartment buildings, is used as the basis for the water-borne waste generation rates used. Solid waste generation data is based on situations considered representative of the community model employed.

### III. COMMERCIAL EQUIPMENT SURVEYS

- Household water requirements can be reduced significantly by employing currently available low water use fixtures and appliances at little or no cost or inconvenience to the user.
- Process instruments, capable of adequately monitoring water in a recycle system for bacteria and viruses, are not currently available. Available bacteria monitors have inadequate response times. Virus detection is generally accomplished manually and incubation periods are required. While development work is being undertaken by NASA and industry, purification systems must preclude the need for such instruments. This can be accomplished by closely tracking simpler measurements such as pasteurization and sterilization temperatures or bactericide concentrations.

### IV. APPLICABLE AEROSPACE TECHNOLOGY

- A wide variety of development programs have been undertaken by NASA and the aerospace industry as a result of the criticality of efficient water and waste management to the design of advanced manned spacecraft. For the most part, resultant systems contain processes that were originally developed for less demanding industrial and commercial applications.

Evaluations revealed that much of the sophistication of aerospace adaptations of water and waste treatment processes is a result of unique requirements for: zero gravity operation, extremely high reliability and minimum weight, volume and power utilization. Great emphasis is placed on systems integration as a means by which spacecraft penalties can be held to absolute minimums. Extensive manned test programs are conducted to evaluate "closed loop" systems. Since there are practical limits on achieving reliability, in-flight maintenance provisions are designed into critical spacecraft systems. Much of the technology developed to adapt water recovery processes to spacecraft requirements, are relevant to the development of advanced integrated urban utilities systems, especially in the detailed design and implementation phases.

### V. COMMUNITY MODEL

- The physical layout of self-contained communities such as the one studied should carefully consider the requirements of utilities systems. This is particularly important from the standpoints of centralizing processing equipment and simplifying collection and distribution networks (a significant cost element).

## VI. COST EVALUATION DATA

- Processes such as distillation and pyrolysis are competitive with physical-chemical treatment only if waste heat is readily available when required. While utilization of the community's power generation waste heat appears appropriate, difficulties arise due to mismatches in availability and demand caused by extreme climates or seasonal changes. Since power generation, heating and air conditioning are the primary elements in overall thermal energy management, their system configurations must be generally defined prior to evaluating the integration of thermal water recovery processes.
- Vacuum sewers are less expensive than gravity sewers on the community site, particularly for reduced flows when black and gray waters are handled separately. This is a result of gravity sewer requirements for larger diameter pipes and for increasing slopes to handle lower flows. Based on filled-pipe operation, vacuum sewers are even less expensive if gray water alone is collected. This type of operation is appropriate only for gray water.
- Water should not be recycled for household reuse if there are community water needs that can be satisfied by waste waters (i.e. irrigation, scrubber water, heat transport fluid, commercial and industrial use).
- Storm water collection and disposal systems should be given strong consideration as a relatively cost free means of conveying and disposing of residual gray water and other treated waste waters. Storm water handling requirements are normally more demanding than those of treated waste water.
- Incineration is the most site-independent means of disposing of refuse and sludges. It is also most appropriate to total energy management systems.

## VII. INTEGRATED SYSTEM CONCEPTS

- Differences in the overall cost of the concepts evaluated are not as dramatic as was anticipated. This is a result of the dominant influence of equipment that is common to all systems studied (i.e. fixtures and appliances, plumbing, waste handling, incineration, etc.)
- Reclamation and reuse is not cost effective in soft water areas having a plentiful, good quality water supply. It appears, however, that it is a practical alternative to conventional approaches in newly constructed or redeveloped communities where water supply and/or waste disposal problems exist.
- The economic value of direct reuse (e.g. dish and clothes washer rinse water used in subsequent wash cycles) is marginal. It is nonetheless included in the selected configuration in consideration of water-short site locations.
- Concepts that collect concentrated black water by a vacuum system and incinerate it directly are most economical in both hard and soft water areas. System concepts that either combine and biologically treat black and gray water, or reuse gray water for toilet flushing prior to treatment, were found to be more expensive.

- Consideration of areas with water resource and waste disposal problems led to the selection of a system characterized by the following:
  - Water conservation: vacuum toilet, flow limiting shower heads and faucets, and front loading clothes washing machines (lower water usage).
  - Direct reuse: dish and clothes rinse water reused for subsequent wash cycles.
  - Waste water collection and transport: separate vacuum collection and transport of gray and black water - common vacuum source.
  - Waste water processing:

Separate incineration of concentrated black water and refuse with heat recovery for power generation.

Subsurface gray water irrigation in growing seasons - treatment to potable quality for limited household reuse during remainder of the year.

The system minimizes water recovery requirements by reducing household use and by recycling only when there is no need for water of less than potable quality.

## VIII. PRELIMINARY DESIGN

- The preliminary design developed by this study is generally applicable to all regions of the country. It is compatible with a wide variety of total energy systems and offers distinct advantages when the two systems are integrated.
- Although the preliminary design was not priced in detail, cost estimates were made for numerous concepts, preparatory to selection for the preliminary design. The concept which is the basis for the preliminary design costs 13 to 29% less than a conventional water and waste management system, depending upon conditions. It uses from 56 to 63% less water and produces as little as 86% less sewage outfall.
- Aside from the potential cost savings of a water and waste management system that makes use of up-to-date technology and a systems approach, housing developments can benefit by substantial reductions in their ecological impact. They can be located on land that is prospectively cheaper. Housing can also be situated in better compliance with planned economic development in water-short regions or those that have pollution problems.
- Aside from the potential cost savings of a water and waste management system that makes use of up-to-date technology and a systems approach, housing developments can benefit by substantial reductions in their ecological impact. They can be located on land that is prospectively cheaper. Housing can also be situated in better compliance with planned economic development in water-short regions or those that have pollution problems.

## X. RECOMMENDATIONS

### Water and Solid Waste Management

The primary recommendation of this study is the eventual construction and testing of an apartment complex incorporating the water and waste management system concept that is described in the Preliminary Design Section of this report. This would be in compliance with the intended follow-on work that was initially expressed in the statement of work for this program.

The test program would be oriented towards proving the validity of the concept as well as acquiring detailed data, such as: utility requirement profiles, accumulator requirements between subsystems with different and/or variable flow rates, operating and maintenance costs of new or modified subsystems and components, system reliability and resident acceptance of the total system and its components.

Implementation of this recommendation should be the culmination of a series of smaller tests and studies. The recommendations that follow are suggested efforts that could be conducted sequentially or simultaneously. The order of arrangement does not imply any priority ranking. Programs that involve the same type of waste water or strongly interface with other subsystems should be efficiently grouped.

### DEVELOPMENT PROGRAMS

#### Vacuum Collection

The Liljendahl vacuum toilet and ancillary collection equipment have been in very limited commercial service for several years. A survey, described in Section III of Volume II, describes a partial recirculation toilet that uses one-seventh as much water per flush as the Liljendahl toilet. Mating this toilet with a vacuum collection system appears feasible but has not been demonstrated. One of the recommended programs for Vacuum Collection is the experimental evaluation of the use of a partial recirculation toilet with a vacuum collection system.

An additional recommendation is the evaluation of gray water collection in filled sewers using a vacuum as the motive force. The data sought is whether solids settling in the line will be transported by liquid velocity or will an occasional air sweep be required to move settled solids satisfactorily. Energy requirements should also be obtained.

#### Incineration

A good method of "treating" and disposing of toilet wastes is incineration. With a partial recirculation toilet and possibly a Liljendahl toilet, the black water quantity is sufficiently small that it appears practical to incinerate black water in the fuel nozzle of a power furnace. The relationship of electrical power requirements to the quantity of black water discharged is such that the incremental fuel needed to vaporize and heat the water to furnace temperatures is about 15% to 30%. The additional energy stored in the water vapor can be recovered in a properly designed system. Furthermore, the heat transfer coefficients are higher with humid gases and permit reductions in heat exchanger surface (and cost). A potential problem is the fouling of heat exchangers with ash from the black water wastes. It is recommended that a series of tests be performed to demonstrate feasibility and to establish parametric performance data on nozzles and the power generation components that are exposed to the combustion gases.

## Subsurface Gray Water Irrigation

Employing gray water for landscape irrigation provides multiple benefits by reducing fresh water requirements and problems associated with final disposal of used water. Because of aesthetic appearance and the possibility of health hazards, it is inappropriate to spray this water onto lawn surfaces. Two subsurface irrigation methods---trickle and moisture barrier irrigation---have been used with fresh water, but not with gray water. The two methods should be evaluated with gray water (settled and unsettled), in various types of soil, with several types of vegetation and in several climates.

## Water Recovery

Reverse osmosis appears to offer economic advantages in reclamation of water from gray water. A number of tests are recommended to demonstrate the suitability of this process and to obtain operating data with the specific type of water to be used as input. They are the determination of:

- operating characteristics of sand core supported membranes, processing gray water without pretreatment.
- The effects on membrane life of various yield percentages (product water divided by input).
- The efficiency of membrane cleaning techniques when fouled by gray water.
- The effectiveness of the membranes as bacterial barriers.

## ANALYTICAL STUDIES

### Generation of Load Profiles

Past and present studies of integrated systems have used averaged system values in specific situations which represent the maximum and minimum condition of a particular parameter. An example is the use of the average cooling load for the peak of the hottest day of the summer in say three regions of the country. What effect the cooling load has at specific hours on the integrated system is not determined, nor is the effect of cooling (or heating) requirements on individual days.

In order to ascertain an integrated system's requirements and benefits with any realism, daily and annual load profiles must be established for: electrical power, heating, cooling, water consumption and waste generation for specific or generalized locations. This suggested program is a prerequisite for the effective performance of the next recommendation.

### Total Energy Concept Development

Total energy systems have been designed and built in the past. Some are still operating while others have failed economically. The first part of this recommendation is the execution of a survey that would correlate thermodynamic considerations with economic success or failure. The second part is the creation of numerous concepts for power generation and heat utilization, using various thermodynamic cycles. Optimization of the thermal parameters would be performed. The concepts would be tested for appropriate performance in residential use.